MANDREL AND METHOD FOR MANUFACTURING COMPOSITE STRUCTURES

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0001] This invention was made with Government support under contract number N00140-95-2-J044 awarded by the U.S. Navy. The government has certain rights in this invention.

BACKGROUND OF THE INVENTION

1) Field of the Invention

[0002] The present invention relates to the manufacture of composite structures and, in particular, to the securing of composite structures such as honeycomb sandwich structures to a mandrel to prevent distortion during manufacture.

2) Description of Related Art

[0003] Composite structures are manufactured for use in a variety of structural applications where the structures provide high stiffness-to-weight and strength-to-weight ratios. For example, a honeycomb core sandwich panel has composite laminate skins that are co-cured with adhesives to opposite sides of a lightweight honeycomb core that can be formed of paper, metal, and the like. Such structures are described in U.S. Patent Nos. 5,284,702; 4,622,091; and 4,353,947, each of which is incorporated herein in its entirety by reference.

[0004] One problem encountered during the manufacture of composite structures relates to the flow of resin from the laminate skin to the core of the structure. Resin is typically provided on or in the skins, and the resin is cured in an autoclave during the co-cure operation. For example, the skins can be formed of a pre-impregnated material, i.e., a prepreg, such as a sheet of a matrix material with a resin disposed

therein. As described in U.S. Patent No. 5,604,010 which is incorporated herein in its entirety by reference, the resin from the skins can flow into the core of the structure during manufacture, thereby reducing the amount of resin in the laminates, and reducing the strength of the laminates. The resin that flows into the core does not add significantly to the strength of the structure. Thus, a heavier panel must be used to achieve a specific desired strength.

[0005] Scrim-supported barrier films are described in U.S. Patent No. 5,604,010 between the fiber-reinforced resin composite laminates and the honeycomb core for preventing the flow of the resin into the core. In addition, U.S. Patent Nos. 5,685,940 and 5,895,699 describe the use of tiedown plies to reduce slipping of the barrier film relative to the core during curing, and both patents are incorporated herein in their entirety by reference. The edges of the tiedown plies can be adhered to one another using a film adhesive with a relatively low cure temperature so that the film adhesive melts and cures at a lower temperature than the resin in the laminates. Thus, the film adhesive can be used to bond the tiedown plies together before the autoclave pressure and temperature are increased during curing of the laminates, thereby retaining the structure in a desired configuration during curing and reducing the likelihood of the core being crushed between the laminates.

[0006] The edges of the tiedown plies are also taped to a mandrel on which the composite structure is disposed to further retain the composite structure to its desired configuration. However, the use of the tape adds to the time and cost of the manufacturing process. Further, in order to sufficiently secure the tiedown plies, each tiedown ply extends beyond the desired size of the structure, with successively higher tiedown plies in a stacked structure extending outwardly beyond each of the lower plies so that each ply can be taped to the mandrel. This requires additional material

for the tiedown plies, and requires additional space on the mandrel for securing each of the tiedown plies.

[0007] Alternatively, grit strips, also referred to as "grip strips," can be provided on the mandrel to increase the friction between the mandrel and the structure and retain the structure in the desired configuration. The grit strips can be formed of a gritty layer, similar to sandpaper, that is secured on the mandrel, or the grit strips can be formed of metal strips that are roughed by forming a plurality of perforations therethrough. However, the grit strips also add to the manufacturing cost. Further, the grit strips can be difficult to clean after use, requiring additional time for cleaning or replacement.

[0008] Thus, there exists a need for an improved mandrel and method for retaining structural members during manufacture. The mandrel and method should be applicable to composite structures such as composite honeycomb structures, and should retain the structure to prevent changes in the configuration of the structure, for example, to prevent core crush. Further, the improvement should preferably not require that the mandrel be significantly larger than the composite structure.

BRIEF SUMMARY OF THE INVENTION

[0009] The present invention provides a mandrel and a method for retaining composite structures, such as composite honeycomb structures, during manufacture. The mandrel defines a layup surface with a grip feature, such as a groove or step, that is configured to engage the composite structure during manufacture and retain the structure in a predetermined configuration. Each of the plies of the composite structure can be secured to the mandrel proximate to the grip feature such that the mandrel need not be significantly larger than the composite structure. Thus, mandrels according to the present invention can be smaller than conventional devices for

forming a composite structure of a given size. The smaller relative size of the mandrel of the present invention can reduce the cost of the mandrel. Further, the smaller size of the mandrel can have a relatively lesser thermal mass, thereby saving energy and time during cure cycles.

[0010] According to one embodiment of the present invention, the mandrel defines an inner portion generally corresponding to a desired contour of the composite structure. The grip feature extends at least partially around the inner portion, for example, to define a boundary of the inner portion having a shape generally corresponding to the desired shape of the composite structure. The grip feature can define a retaining surface generally perpendicular to the layup surface and an edge between the layup surface and the retaining surface. The retaining surface and the edge are configured to engage the composite structure. For example, the grip feature can be a groove disposed in the layup surface defining a boundary between the inner portion and an outer peripheral portion of the layup surface. Alternatively, the grip feature can define a bottom that extends from the retaining surface to a periphery of the mandrel.

[0011] According to one method of the present invention, a mandrel defining a layup surface for receiving the composite structure is provided. A composite preform is assembled on the layup surface with at least one resinous laminate and at least two tiedown plies. At least one of the tiedown plies is adhered to the mandrel with the film adhesive, which is applied at the grip feature so that the tiedown ply is engaged by the grip feature and the grip feature retains the composite structure in a predetermined configuration.

[0012] For example, the laminate can include a bismaleimide (BMI) matrix resin. A barrier film of a bondable grade polyimide can also be provided adjacent the

laminate, with an adhesive between the barrier film and a honeycomb core of the preform. Further, a film adhesive layer can be provided between the barrier film and the laminate, and/or a supporting scrim can be provided between the barrier film adhesive and the core to prevent sagging of the barrier film into the core cells. One or more of the tiedown plies can be placed between the adhesive and core so that the tiedown ply is in contact with the core.

[0013] The film adhesive is characterized by a cure temperature lower than a cure temperature of the resin of the laminate. Thus, the composite preform can be heated to a first temperature between the cure temperature of the film adhesive and the cure temperature of the resin in the laminate, and subsequently to a temperature at least as high as the cure temperature of the resin so that the film adhesive is cured before the resin is melted. After the resin in the laminate is cured, the preform can be trimmed along a trim line inward of the grip feature to form the composite structure having a predetermined shape.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0014] Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

[0015] Figure 1 is a partial section view illustrating a mandrel with a preform for forming a composite structure thereon according to one embodiment of the present invention;

[0016] Figure 1A is a partial section view illustrating a composite structure disposed on a planar mandrel;

[0017] Figure 2 is a partial section view illustrating a composite structure formed according to one embodiment of the present invention;

[0018] Figure 3 is a plan view illustrating the mandrel of Figure 1;

[0019] Figure 4 is a section view illustrating the mandrel of Figure 1 as seen along line 4-4 of Figure 3;

[0020] Figure 5 is a section view illustrating a mandrel according to another embodiment of the present invention; and

[0021] Figure 6 is a block diagram illustrating the operations for forming a composite structure according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0022] The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

[0023] Figure 1A illustrates a composite structure **10** during a conventional manufacture process known in the art. As shown, the structure **10** is formed of a core **12** that is sandwiched between laminar skins **14** disposed on a planar mandrel **20**. The laminar skins **14** are formed of a plurality of layers of plies **16, 18**, with some of the plies, referred to as tiedown plies **18**, extending outward from the structure **10**. The plies **16, 18** are resin-impregnated laminar sheets. For purposes of illustrative clarity, the thickness of the laminar skins **14** is exaggerated, with space shown between the plies **16, 18**, though in practice the plies **16, 18** are disposed substantially against one another. Each of the tiedown plies **18** is taped to the mandrel **20**, such as by using 2-inch wide pieces **22** of Kapton® tape, a registered trademark of E. I. Du Pont De Nemours and Company. Advantageously, each successive tiedown ply **18** extends to

a successively greater length than the lower tiedown plies **18**, i.e., the plies **18** closer to the mandrel **20**. Thus, each tiedown ply **18** extends beyond the edges of the lower tiedown plies **18** so that the tape adheres each tiedown ply **18** directly to the mandrel **20**. Further, an epoxy film adhesive **19** disposed between the adjacent tiedown plies **18** is configured to connect the plies **18**. The film adhesive **19** can be configured to cure at a temperature less than the cure temperature of the resin in the laminate skins **14**. During manufacture, the structure **10** is heated to a first temperature to cure the film adhesive **19** between the tiedown plies **18** without melting the resin in the laminate skins **14**. Then, with the film adhesive **19** cured and connecting the tiedown plies **18**, the structure **10** is heated to a second, higher temperature, at least as high as the cure temperature of the resin in the skins **14** to cure the skins **14** and thereby form the structure **10**. After the structure **10** has been cured and cooled, the composite structure **10** is removed from the mandrel **20** and the tiedown plies **18** are trimmed to remove the film adhesive **19** and the extending portions of the tiedown plies **19** from the finished structure **10**.

[0024] Referring now to Figure 1, there is shown a preform **100** for forming a composite structure **110** according to one embodiment of the present invention and, in particular, a honeycomb core sandwich panel having a core **112** with outer facesheets or skins **114** on opposite sides thereof. One finished composite structure **110** according to the present invention is illustrated in Figure 2, but it is understood that composite structures having various structures and configurations can similarly be formed without departing from the scope of the present invention. The composite structures **110** formed according to the present invention can be used for a variety of applications, including aerospace structures, automobiles, other vehicles, and other

applications where high stiffness-to-weight and strength-to-weight ratios are desirable.

[0025] The skins **114** of the composite structure **110** comprise resinous composite laminates, i.e., laminates formed of layers of fiber-reinforced organic matrix resin, which are in a cured and consolidated form in the finished skins **114**. The skins **114** can be provided as prepreg sheets in the preform **100** or as reinforcement sheets with separate resin films therebetween. The core **112** can be paper, synthetic paper, metal, composite, or the like, as appropriate for a particular application. At least one tiedown ply **116, 116a** is disposed between the core **112** and the outermost layer of each laminate skin **114**. An unsupported film adhesive **118**, a barrier film **120**, and a scrim-supported film adhesive **122** can also be provided between the skin **114** and the core **112** to keep resin out of hollow cells that are defined by the core **112**. The tiedown plies **116, 116a** extend from the preform **100** for securing the preform **100** during manufacture, e.g., to prevent core crush that can otherwise result when the preform **100** is subjected to pressure and heat associated with curing. Further, one or more of the tiedown plies **116a** can contact the core **112**, for example, on a chamfered portion **113** of the core **112**, where the thickness of the core **112** tapers to an edge, as shown in Figure 1.

[0026] For example, the laminated skins **114** can be formed of RIGIDITE® 5250-4-W-IM7-GP-CSW, RIGIDITE® 5250-4-W-IM7-GP-CSX, or RIGIDITE® 5250-4-W-IM7-GP-PW prepreg from Cytec Engineered Materials, Inc. (Cytec). Alternatively, the laminated skins **114** can be provided as laminar sheets with a resin disposed separately therewith. The film adhesive **122** can be 0.015 psf METLBOND® 2550U adhesive, also available from Cytec. The film adhesive **118** provides additional resin to promote bonding between the laminate skin **114** and

barrier film **120**. The barrier film **120** can be a 0.001 inch thick, bondable grade, surface-treated KAPTON® polyimide barrier film capable of withstanding the cure cycle to provide a resin-impermeable membrane between the skin **114** and the core **112**. The scrim-supported film adhesive **122** can be 0.06 psf METLBOND® 2550G adhesive, available from Cytec, with a fiberglass scrim such as "Style 104" fiber cloth. The scrim-supported film adhesive **122** prevents the barrier film **120** from bulging into the cells of the core **112**, thereby retaining the resin in the laminate skins **114** so that the cured skin thickness is maximized, and achieving maximum performance for minimum weight of the composite structures. The film adhesive **118**, barrier film **120**, and film adhesive **122** can be purchased as a single item from Cytec as METLBOND® 2550B-0.082 36. Preferably, the film adhesive **118** is tailored to achieve an adequate bond between the skin **114** and barrier film **120**. The supported film adhesive **118** and barrier film layers **120** in the sandwich structure also function as corrosion barriers between the skin **114** and core **112** in the case where the core **112** is metal, such as aluminum, and the skin **114** includes a galvanically dissimilar material, such as carbon fiber.

[0027] Additional information concerning composite structures is presented in a technical paper by Hartz, et al., "Development of a Bismaleimade/Carbon Honeycomb Sandwich Structure," SAMPE, March, 1996, which is incorporated herein by reference. This paper describes the use of a barrier film, tiedown plies, and adhesion of layers in a composite structure.

[0028] The honeycomb core **112** can be a HRP Fiberglass Reinforced Phenolic honeycomb available from Hexcel. The core **112** can be preconditioned to eliminate volatile evolution during curing. For example, the core **112** can be heated to about 235° C prior to laying up the preform **100**. Such preconditioning can eliminate

disbonding of the core **112** and laminate skins **114** caused by outgassing of the core **112** during curing, especially for phenolic cores **112**.

[0029] The tiedown plies **116, 116a** typically are prepregs of carbon fiber impregnated with bismaleimide thermoset resin, although the present invention also applies to other resin systems. For example, tows can be used instead of the prepreg plies. As shown in Figure 2, the tiedown plies **116, 116a** can be laminar sheets that extend continuously or partially through the preform **100** to anchor the preform **100** during manufacture. For example, the tiedown ply **116a** is a narrow, peripheral strip that contacts the core **112** along at least part of the chamfered portion **113** for about 1 inch overlap with the core **112** and extends outward from the core **112** beyond a net trim line **124**, i.e., the line along which the tiedown plies **116, 116a** are trimmed from the composite structure **110**. Thus, the tiedown ply **116a** forms a peripheral frame around the edge of the composite structure **110** and allows an adhesive interface between the core **112** and the skins **114**. The tiedown ply **116a** can be disposed against either side of the core **112** and contacts the core **112** beneath the adhesives **118, 122** and barrier film **120**, which bond the laminate skin **114** to the core **112**. Tiedown plies are also described in U.S. Patent No. 5,685,940.

[0030] Each of the tiedown plies **116, 116a** can have about the same outer dimensions so that the plies **116, 116a** extend to about a common edge beyond the net trim line **124**. Alternatively, each tiedown ply **116, 116a** can extend successively outward beyond the underlying plies **116, 116a**. A film adhesive **126** is disposed between the tiedown plies **116, 116a** to retain the plies **116, 116a** to one another and prevent movement of the plies **116, 116a** relative to the other plies **116, 116a** when pressure is applied during the autoclave curing cycle. The film adhesive **126** can be disposed outside the net trim line **124** and removed from the finished composite

structure **110**. The film adhesive **126** can have a relatively low cure temperature, e.g., about 121° C for BMI structures. Thus, the film adhesive **126** is cured at a temperature that is about 38° to 66° C below the cure temperature of the resin in the laminate skins **114** so that the tiedown plies **116, 116a** are adhered before the autoclave pressure is increased for curing of the skins **114**.

[0031] During manufacture, the preform **100** is assembled, or layed-up, on a mandrel **130**, shown individually in Figures 3 and 4. The mandrel **130** defines a layup surface **132** for receiving the preform **100** and, hence, the composite structure **110**. The layup surface **132** defines an inner portion **134** and a grip feature **140**. The inner portion **134** generally corresponds to a desired contour of the composite structure **110**. For example, the flat layup surface **132** illustrated in Figures 3 and 4 can be used to manufacture composite structures **110** that are generally flat on at least one side. Alternatively, the layup surface **132** can be contoured to define simple or complex geometric shapes including nonplanar angles, curves, and the like. As shown in Figure 4, the grip feature **140** can be a groove disposed in the layup surface **132** that defines a boundary between the inner portion **134** and an outer peripheral portion **136** of the mandrel **130**. The outer peripheral portion **136**, which extends outwardly from the inner portion **134**, can be used to receive and/or secure the edges of the tiedown plies **116, 116a** outward of the net trim line **124**, i.e., a trim portion of the preform **100** that is removed after curing to form the composite structure **110** to the desired shape and dimensions.

[0032] As shown in Figure 3, the grip feature **140** is a groove that extends continuously around the entire inner portion **134** of the layup surface **132**, though in other embodiments, the grip feature **140** can be formed of multiple distinct grooves, for example, four linear grooves disposed parallel to the edges of the mandrel **130** that

are not joined at the corners of the mandrel **130**. Further, the grip feature **140** can define an outer perimeter of the composite structure **110**, disposed outside the net trim line **124** and corresponding to the desired shape of the composite structure **110**. The inner portion **134** of the layup surface **132** is shown to be generally rectangular-shaped in Figure 4, but other shapes can be defined by the grip feature **140** and the inner portion **134**, including complex shapes having curves or angles at the periphery.

[0033] The grip feature **140** is configured to retain the composite structure **110** in a predetermined configuration during manufacture. As shown in Figure 4, the grip feature **140** defines a retaining surface **142** proximate to the inner portion **134** of the layup surface **132**. The retaining surface **142** is generally perpendicular to the layup surface **132** so that the retaining surface **142** and the layup surface **132** define an edge **144** therebetween. The retaining surface **142** and the edge **144** are configured to engage the composite structure **110**. In particular, the feature **140** is configured to receive a film adhesive **146** or other adhesive material, which is secured to the mandrel **130** in the feature **140** and thereby secures the tiedown plies **116, 116a** to the mandrel **130**. The feature **140** can also partially receive one or more of the tiedown plies **116, 116a** therein. The film adhesive **146** can be the same as the adhesive **126** between the tiedown plies **116, 116a**. Preferably, the film adhesive **146** also has a cure temperature less than the cure temperature of the resin of the skins **114** so that the film adhesive **146** can be cured before the skins **114**, thereby securing the plies **116, 116a** to the mandrel **130**. For example, the film adhesive **146** can have a cure temperature that is about 38° to 66° C below the cure temperature of the resin in the laminate skins **114**. Preferably, the difference in temperature between the cure temperature of the film adhesive **146** and the resin in the laminate skins **144** is such that the adhesive **146** can gel or vitrify before the resin in the laminate skins **144**

becomes substantially cured. The bonds provided by the cured adhesives **126, 146** are sufficiently strong so that the adhesive **146** retains one of the tiedown plies **116** to the mandrel **130** and the adhesive **126** retains the remaining tiedown plies **116, 116a** to the ply **116** attached to the mandrel **130**. Thus, the film adhesive **146** retains the tiedown plies **116, 116a** while the preform **100** is cured, reducing movement of the tiedown plies **116, 116a** and skins **114**. The present invention therefore provides an apparatus and method for reducing wrinkling of the skins **114**, crushing of the core **112**, and/or other undesirable movement of the preform **100** during curing.

[0034] A bottom portion **148** of the feature **140** is angled relative to the retaining surface **142**, e.g., parallel to the layup surface **132** of the inner portion **134**. The feature **140** can also define a tapered portion **150** that is angled from the bottom portion **148** to the surface of the peripheral portion **136**. The angle of the tapered portion **150** can facilitate the removal of the composite structure **110** from the mandrel **130** and the film adhesive **146** from the feature **140** after curing. Alternatively, the bottom portion **148** can taper to the surface of the outer peripheral portion **136**, or the angled portion **150** can be perpendicular to the bottom and/or outer peripheral portions **148, 136**.

[0035] In other embodiments of the present invention, the grip feature **140** can define a variety of other cross-sectional profiles, including rounded, square, or triangular grooves, and the like. Further, the grip feature **140** can define profiles other than grooves. For example, Figure 5 illustrates another mandrel **130** with a step-like grip feature **140**. As shown in Figure 5, the bottom **148** of the feature **140** can extend from the retaining surface **142** to a periphery **152** of the mandrel **130**, i.e., so that the mandrel **130** does not define an peripheral portion extending outward from the feature **140**. In addition, although the retaining surface **142** is shown to be perpendicular to

the layup surface **132**, the retaining surface **142** can alternatively define an acute or obtuse angle relative to the layup surface **132**, i.e., the retaining surface **142** can be angled toward or away from the outer peripheral portion **136**. Preferably, the retaining surface **142** is sufficiently angled relative to layup surface **132** so that the retaining surface **142** is configured to engage the composite structure **110**.

[0036] The grip feature **140** can be formed in a variety of sizes. For example, the feature **140** can define a depth of between about 0.070 inch and 0.5 inch, such as between about 0.100 inch and 0.250 inch. In one embodiment, the feature **140** has a depth that is about 0.0625 inch less than the thickness of the mandrel **130**, which is typically at least about 0.25 inch. The width of the feature **140**, as measured between the inner portion **134** and the outer portion **136** or the periphery **152** of the mandrel **130**, can also vary. For example, the width of each of the bottom and tapered portions **148**, **150** can be at least about 0.5 inch, and the width of the feature **140** can be about 1 inch.

[0037] The operations for retaining a composite structure during manufacture according to one embodiment of the present invention are illustrated in Figure 5. It is understood that additional operations can be performed and one or more of the illustrated operations can be omitted without departing from the scope of the present invention. In Block **210**, a mandrel is provided. The mandrel defines a layup surface for receiving the composite structure thereon, and the layup surface defines an inner portion and a grip feature. The grip feature can be formed to extend continuously around the inner portion, and can define a retaining surface that forms an edge with the inner portion of the layup surface.

[0038] Next, a composite preform in the shape of the composite structure is assembled on the layup surface of the mandrel. See Block **212**. The preform has at

least one resinous composite laminate and at least two tiedown plies. For example, the tiedown plies can include a bismaleimide matrix resin. The preform can also include a barrier film of a bondable grade polyimide adjacent the laminate. For example, the preform can include a honeycomb core, and an adhesive can be disposed between the barrier film and the core. Further, a film adhesive layer can be disposed between the barrier film and the laminate. In addition, a supporting scrim can be provided between the barrier film adhesive and the core to prevent sagging of the barrier film into the cells of the honeycomb core. One or more of the tiedown plies can contact the core between the adhesive and core.

[0039] At least one of the tiedown plies is adhered to the mandrel with the film adhesive applied at the grip feature so that the tiedown ply is engaged by the grip feature and the grip feature retains the composite structure in a predetermined configuration. See Block **214**. The preform is cured, for example, in an autoclave, to form the composite structure. That is, the preform is subjected to a cycle of elevated temperature and pressure to consolidate and cure resin in the laminate while bonding or otherwise adhering the cured laminate to the honeycomb core. The film adhesive is characterized by a cure temperature lower than a cure temperature of the resin of the laminate. Thus, the film adhesive can be cured before the resin of the composite laminate is melted. See Block **216**. For example, the composite preform is heated to a first temperature that is between the cure temperature of the film adhesive and the cure temperature of the resin in the composite laminate, e.g., about 135° C, and held for a first duration, e.g., about 2 hours. The preform is then further heated to a second temperature that is at least as high as the cure temperature of the resin, e.g., 191° C, and held for a second duration, e.g., between about 6 and 12 hours. The preform can also be further heated to complete curing.

[0040] Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.